技術論文

The Tire Characteristic Effect on Motorcycle Maneuverability Using a Riding Simulator

Masayuki Miki Tetsuya Kimura

当論文は、JSAE 20179018 / SAE 2017-32-0018として、SETC2017（Small Engine Technology Conference）にて発表されたものです。

要旨

車両の旋回性能を表す指標としてスタビリティファクタは四輪では広く利用されている。二輪においても同様の考え方より旋回性能を示す指標としてスタビリティファクタが提案されている。また、二輪車の官能評価としてのライントレース性評価ではアンダーステア、オーバーステアと表現することがあるが、スタビリティファクタとの関連が調べられていない。本稿ではライディングシミュレータを用いて前後タイヤの滑り角特性を変えた実験を行い、ライントレース性についてスタビリティファクタとライダーの官能評価との相関を調査し、評価指標の検討を行った。

Abstract

The stability factor is widely used for four-wheel vehicles as an index representing the turning performance of a vehicle. Stability factor for two-wheel vehicles has been proposed as an indicator of cornering performance from the same way of thinking. In line traceability evaluation as a sensory evaluation item of motorcycles, the expressions of understeer and oversteer are sometimes used, but the relation with stability factor for two-wheel vehicles has not been investigated. In this paper, a test in which the slip angle characteristics of the front and rear tires were varied using a riding simulator was conducted, and the correlation between the stability factor and the rider evaluation was investigated to derive an index showing the line traceability.

1 INTRODUCTION

The stability factor is widely used with four-wheel vehicles as an index of turning performance. Based on the same concept, the stability factor for two wheel vehicles[1] has been proposed as an index of turning performance for motorcycles as well. Understeer and oversteer are sometimes used in line traceability evaluations for sensory evaluations of motorcycles. However, the relationship with the stability factor has not been investigated. In this paper, a riding simulator was used and tests with different slip angle characteristics for the front and rear tires were performed in order to investigate the correlation between the stability factor and rider sensory evaluation and derive an evaluation index for line traceability.

2 TEST METHODS AND RESULTS

2-1. Test Methods

With motorcycles, the slip angle is extremely small and its measurement and reproduction are extremely difficult. Therefore, the tests were performed using a riding simulator[2] that can measure the slip angle, provide high reproducibility, and allow riding evaluations by the riders. The riding simulator used in the test is shown in Figure 1.

Fig. 1 Riding simulator.

The model used for evaluation was a large-size sports tourer with engine displacement of 1,300 cc. The evaluation course was an oval course with R30 curves as shown in Figure 2.

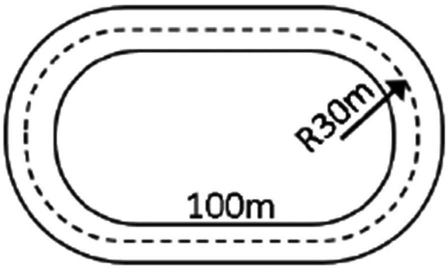

Fig. 2 Test course image.

The riding method was constant-speed driving at 50 km/h, and the evaluation was conducted by tracing the R30 line that was marked on the center of the course. An evaluation score method was used for the rider evaluation. For line traceability during constant turning in the curves, a path on the outside of the target line was considered understeer, and a path on the inside of the line was considered oversteer. The scores from +2 to -2 were used so that positive values indicate understeer, negative values indicate oversteer, and 0 indicates neutral.

The test was conducted by three evaluation riders who were experts capable of evaluating steering stability.

2-2. Tire Characteristics

The lateral force of a motorcycle is a combination of a camber thrust and a cornering force, and during the steady circle turning, the roll angle and the camber thrust are determined by the balance between the vehicle body weight and the centrifugal force, and the rider is adjusting with the cornering force. In this time we treated the slip angle as the vehicle parameter of lateral force generation because we fixed the driving conditions and the vehicle. The combinations of tire characteristics consisting of 4 front wheel specifications and 2 rear wheel specifications, each with different camber thrust coefficients, were used to prepare 8 types of slip angle characteristics(Table 1) with combining the direction of the slip angle of the front and rear wheels and the magnitude relation of the front and rear wheels. The slip angle characteristics and stability factor for each of these are shown in Table 2.

The stability factor was found in advance based on formulas (1) and (2) by using the effective steering angles during R30 constant turning driving at a speed of 50 km/h.

Table 1 Test condition of tire select.

No	Specification	Tire type	
		Fr	Rr
1	Fr slip angle inside <Rr slip angle outside	Spec A	Spec a
2	Fr slip angle inside >Rr slip angle outside	Spec D	Spec a
3	Fr slip angle outside<Rr slip angle inside	Spec B	Spec b
4	Fr slip angle outside>Rr slip angle inside	Spec C	Spec b
5	Fr slip angle outside<Rr slip angle outside	Spec B	Spec a
6	Fr slip angle outside>Rr slip angle outside	Spec C	Spec a
7	Fr slip angle inside <Rr slip angle inside	Spec A	Spec b
8	Fr slip angle inside >Rr slip angle inside	Spec D	Spec b

$$\delta_0 = l / R \qquad (1)$$

$$K_\delta = (\delta / \delta_0 - 1) / v^2 \qquad (2)$$

where,

δ_0: Geometrical steering angle K_δ: Stability factor
l: Wheel base δ: Front wheel effective steering angle
R: Turning radius v: Vehicle speed
Coodinate: ISO11838

The relationship between stability factor K_δ and understeer, neutral steer, and oversteer is as shown below.

$K_\delta > 0$: Understeer
$K_\delta = 0$: Neutral steer
$K_\delta < 0$: Oversteer

Table 2 Stability factor value (R30, 50 km/h)

No	Effective steering angle(deg)	Fr slip angle(deg)	Rr slip angle(deg)	Steer torque (Nm)	Stability factor
1	2.5	0.21	−0.12	−16.4	−0.0006
2	2.1	0.69	−0.13	−18.9	−0.0015
3	4.1	−0.62	0.61	−10.8	0.0023
4	5.6	−2.13	0.59	−4.9	0.0050
5	3.4	−0.62	−0.10	−10.5	0.0010
6	4.9	−2.11	−0.11	−4.8	0.0037
7	3.4	0.20	0.59	−16.9	0.0007
8	2.8	0.69	0.57	−19.2	−0.0002

2-3. Test Results

Correlation analysis was performed of the stability factor and rider sensory evaluation results. The results are shown in Table 3.

Table 3 Rider score and correlation analysis result.

		Rider score			
	Stability factor	Rider A	Rider B	Rider C	Average
1	−0.0006	1.0	1.0	1.0	1.0
2	−0.0015	1.5	0.5	2.0	1.3
3	0.0023	−0.5	0.5	−1.0	−0.3
4	0.0050	−2.0	−1.0	−1.5	−1.5
5	0.0010	−1.0	0.0	−0.5	−0.5
6	0.0037	−2.0	−0.5	−2.0	−1.5
7	0.0007	1.0	1.5	2.0	1.5
8	−0.0002	2.0	1.5	2.5	2.0
Correlation coefficient between stabilityfactor and rider score		−0.90	−0.77	−0.86	**−0.84**
	p value	0.00	0.03	0.01	**0.01**

The coefficient of correlation between the stability factor and rider evaluation result was a highly negative correlation of -0.84, indicating the possibility that stability factor can be used as an index of turning performance. However there remain concerns due to the fact that understeer and oversteer are reversed, and due to the rank characteristics of the different specifications. Figure 3 shows a graph of the sign reversed stability factor and the rider evaluation results reordered in order of the rider evaluations. Although specifications 7 and 8 show more understeer than specification 2 in the rider evaluations, the sign reversed stability factors indicate oversteer, showing a large discrepancy.

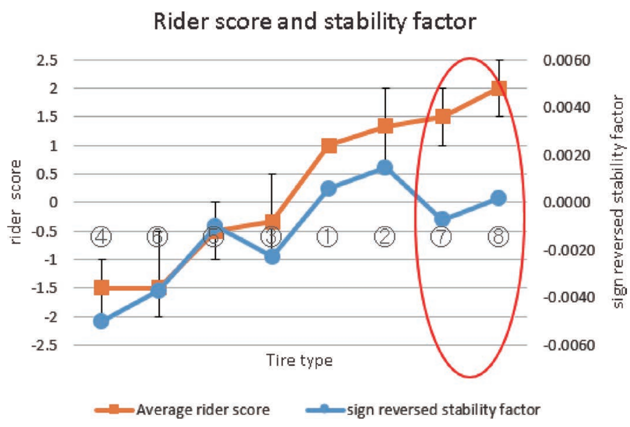

Fig. 3 Rider score and stability factor.

In order to satisfy the rank characteristics, it was deemed necessary to conduct a separate study of evaluation index for expressing line traceability.

3 STUDY AND VERIFICATION OF LINE TRACEABILITY EVALUATION INDEX

3-1. Index Study

The first object of our study was the stability factor which was a turning characteristic value. From the stability factor formula (2), it is obtained that the effective steering angle expresses the turning characteristic of each vehicle if the driving conditions are constant. Because this paper focuses on the front and rear slip angles, Formula (1) is transformed so that it can be expressed using the slip angle.

The slip angles α_1 and α_2 of the front and rear wheels are defined as follows.

$$\alpha_1 = \beta + l_f \omega / V - \delta \quad (3)$$

$$\alpha_2 = \beta - l_r \omega / V \quad (4)$$

α_1: Front wheel slip angle

α_2: Rear wheel slip angle

ω: Yaw rate

l_r: Distance between center of gravity and rear wheel

l_f: Distance between center of gravity and front wheel

β: Vehicle slip angle

When Formulas (3) and (4) are organized for the front wheel effective steering angle δ, the result is the following formula.

$$\delta = \alpha_2 - \alpha_1 + l / R \quad (5)$$

Inserting Formula (5) into Formula (2) produces Formula (6). This shows that the stability factor can be expressed as the ratio of the difference between the front and rear slip angles compared to the geometrical steering angle.

$$K_\delta = (\alpha_2 - \alpha_1) / \delta_0 / v^2 \quad (6)$$

Where the rider evaluations are concerned, the riders sensed the differences in the above turning characteristic.

However, the evaluation scores were deemed to be different from the stability factor. Therefore, a multiple regression analysis of the relationship between the front/rear slip angles and rider evaluations was conducted to derive a line traceability evaluation index that can be expressed by the front/rear slip angles.

3-2. Results of the Evaluation Index Study

Based on the earlier test results, a multiple regression analysis taking the front/rear slip angles as the explanatory variables and the rider evaluations as the objective variables was conducted. The results are shown in Table 4.

Table 4 Result of multiple regression analysis.

		Rider A	Rider B	Rider C	All rider
Coefficient	Fr slip angle	1.22	0.55	1.25	1.01
	Rr slip angle	0.97	1.28	1.52	1.25
p value	Fr slip angle	0.00	0.04	0.01	0.00
	Rr slip angle	0.12	0.08	0.13	0.01

In Formula (6), the coefficient for the front and rear slip angles is negative for the front wheel and positive for the rear wheel, and the front/rear balance was equal. In contrast, the coefficients derived here are both positive, which presents that the front wheel coefficient tends to be larger.

The coefficients for each of the three riders were different, and when feedback of the results to each rider was performed, the riders commented that the results were similar to the feeling they experienced during the evaluations that the coefficient for the wheel that was of greater focus was higher.

Then, all of the rider results were collected and defined as the line traceability evaluation index K_δ' as shown in Formula (7).

$$K_\delta' = sgn(\delta)\,(1.01\alpha_1 + 1.25\alpha_2) \qquad (7)$$

The results from application of this evaluation index are shown in Figure 4.

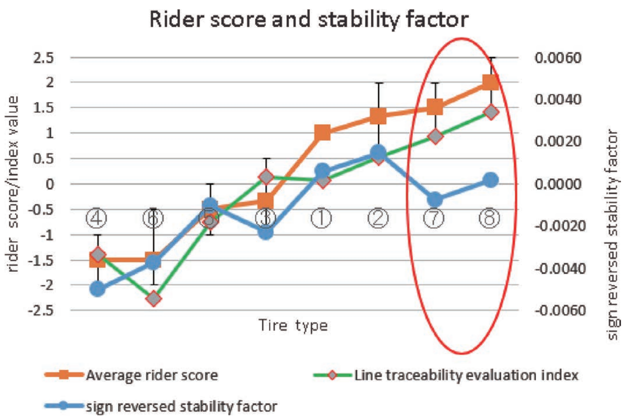

Fig. 4 Rider evaluation result and stability factor.

The graph shows that the rank characteristics of the different specifications that were previously a concern have been resolved. Quantitatively, when the correlation coefficient and rank correlation coefficient for the rider evaluations are compared, the results show that the overall correlation and rank correlation of this evaluation index are higher than the sign reversed stability factor.

Table 5 shows the correlation coefficient, rank correlation coefficient, and p values for the sign reversed stability factor and line traceability index.

Table 5 Correlation coefficient and rank correlation coefficient.

	Sign reversed stability factor	Line traceability evaluation index
Correlation coefficient	0.82	0.88
p value	0.01	0.00
Rank correlation coefficient	0.80	0.87
p value	0.02	0.01

3-3. Evaluation Index Verification Method

To verify the evaluation index shown in Formula (7), verification tests were conducted by using different slip angle characteristics and different driving conditions. The evaluation course was the same oval course as the previous test, and two courses were prepared (R30 and R100) according to the evaluation speed. The driving speed was constant and was 50 km/h on the R30 oval and 82 km/h on the R100 oval. Nine slip angle characteristic specifications were created from combinations of three front wheel specifications and three rear wheel specifications. The slip angle characteristics and stability factors are shown in Table 7. The evaluation rider was a single expert rider.

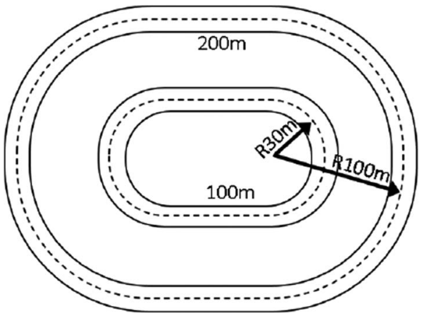

Fig. 5 Test course image.

Table 6 Test tire characteristics.

No	Tire type: Fr	Tire type: Rr
1	Spec A	Spec a
2	Spec C	
3	Spec B	
4	Spec A	Spec b
5	Spec C	
6	Spec B	
7	Spec A	Spec c
8	Spec C	
9	Spec B	

Table 7 Stability factor value.

R30 50km/h

No	Effective steering angle(deg)	Fr slip angle(deg)	Rr slip angle(deg)	Steer torque(Nm)	Stability factor
1	2.5	0.21	−0.12	−16.4	−0.0006
2	2.1	0.69	−0.13	−18.9	−0.0015
3	3.4	−0.62	−0.10	−10.5	0.0010
4	2.6	0.21	−0.02	−16.3	−0.0004
5	2.2	0.69	−0.03	−18.8	−0.0013
6	3.5	−0.62	0.00	−10.4	0.0012
7	2.8	0.20	0.16	−16.0	0.0000
8	2.4	0.68	0.16	−18.5	−0.0009
9	3.7	−0.63	0.19	−10.2	0.0016

R100 82km/h

No	Effective steering angle(deg)	Fr slip angle(deg)	Rr slip angle(deg)	Steer torque(Nm)	Stability factor
1	0.5	0.22	−0.07	−10.2	−0.0007
2	0.2	0.56	−0.07	−12.0	−0.0015
3	1.1	−0.32	−0.05	−5.6	0.0007
4	0.6	0.22	0.00	−10.1	−0.0005
5	0.3	0.56	0.00	−11.9	−0.0014
6	1.2	−0.33	0.02	−5.5	0.0009
7	0.8	0.21	0.15	−9.9	−0.0002
8	0.4	0.56	0.14	−11.7	−0.0010
9	1.3	−0.33	0.17	−5.4	0.0012

3-4. Results of Evaluation Index Verification

The verification results are shown in Figure 6.

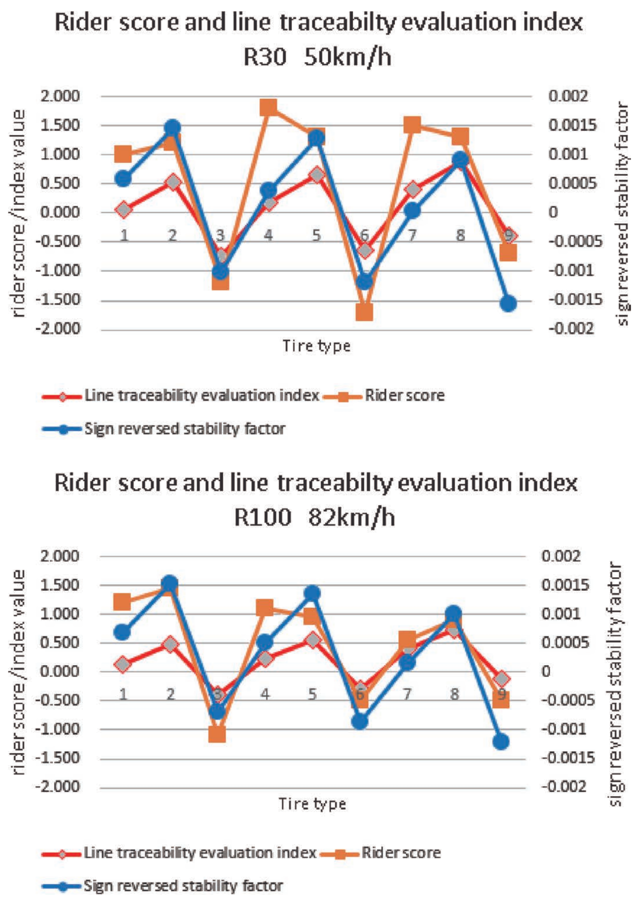

Fig. 6 Rider score and stability factor.

The correlation coefficient and rank correlation coefficient for the line traceability index and sign reversed stability factor with regards to the rider evaluation results are shown in Table 8.

Table 8 Correlation coefficient and rank correlation coefficient.

	Tire different evaluation		Driving condition different evaluation	
	R30 50km/h		R100 82km/h	
	Sign reversed stabilityfactor	Line traceability evaluation index	Sign reversed stabilityfactor	Line traceability evaluation index
Correlation coefficient	0.84	0.88	0.90	0.87
p value	0.01	0.00	0.00	0.01
Rank correlation coefficient	0.48	0.72	0.78	0.82
p value	0.22	0.05	0.02	0.01

In the test results both with different slip angles and different speeds, the correlation of the line traceability index and rider evaluation results was high, at 0.88 and 0.87. There was also high correlation of the sign reversed stability factor and rider evaluation results, at 0.84 and 0.9. For the rank correlation coefficient, the correlation between the line traceability index and rider evaluation results was high, at 0.72 and 0.82, and was higher than the sign reversed stability factor by +0.24 and +0.04 points, indicating specification rank characteristic more clearly.

Based on the above, it is considered that the line traceability evaluation index is a useful index, at least under the driving conditions used in this test.

4 CONCLUSIONS

In this paper, a series of tests was conducted using a riding simulator with different front and rear tire slip angle characteristics, and the correlation between the stability factor and rider evaluation for line traceability was investigated. Also, a study was conducted on the evaluation index based on the front and rear tire slip angles as an evaluation index that expresses line traceability. The results of these tests indicated the following.

(1) There is a high negative correlation between the stability factor and rider evaluations, however there is a large discrepancy in the rank characteristic when different specifications are used.

(2) It was hypothesized that the front/rear tire slip angle characteristic affects turning motion. Multiple regression analysis was performed from the rider evaluation results and front/rear slip angles to derive a line traceability evaluation index. It was confirmed that applying this index yields higher correlation and rank correlation with the rider evaluations, and the discrepancy caused by the rank difference that had previously been a concern was resolved.

(3) Verification tests of the derived line traceability evaluation index were conducted using different tire specifications and different driving conditions, and high correlation and rank correlation were confirmed.

(4) It is considered that the derived line traceability evaluation index is a useful index, at least under the driving conditions used in this test.

This study was investigated and approved by the Yamaha Motor Ethics Investigation Committee. (Investigation and approval number: 0046)

Informed consent procedures were conducted for all test participants.

REFERENCES

[1] Ichiro Kageyama: Study on performance index for two-wheeled vehicle behavior, Proceedings of JSAE Annual Congress (Autumn), 2007, 150-07, pp.13-18.
[2] Yasunobu Harazono, Tetsuya Kimura, Hitoshi Watanabe: Research on the Simulation of Low Speed by a Riding Simulator for Motorcycle, Proceedings of JSAE Annual Congress (Spring), 2013, 16-13, pp.1-6.

■著者

三木 将行
Masayuki Miki
技術・研究本部
研究開発統括部
基盤技術研究部

木村 哲也
Tetsuya Kimura
技術・研究本部
研究開発統括部
基盤技術研究部